International Conference on Renewable Energies and Power Quality (ICREPQ'16)
Madrid (Spain), 4th to 6th May, 2016
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.14 May 2016

Thermal Experimental Investigation on Air Cooled PV Panel

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Abstract. The cooling of PV panels has the potential to reduce the cost of solar energy. By proper circulation of a fluid with low inlet temperature, heat can be extracted from PV modules, keeping the electrical efficiency at satisfactory values. In this paper, the dynamic of air cooled PV panels' temperature are experimentally investigated. The following measurements were made: a) the PV panel open circuit voltage decreasing, in the absence of the cooling air forced circulation, from the moment when the PV panel was exposed to the Sun; b) the PV panel open circuit voltage increasing, in the presence of the cooling air forced circulation, starting from the initial value due of the captured solar radiation, measured in the absence of the cooling air forced circulation; c) the PV panel front temperature distribution during the increasing and decreasing of the panel temperature. Based on the results of these measurements, the parameters of a simple dynamic thermal model of the PV panel were estimated.

Key words

photovoltaic energy, air cooling, thermal model.

1. Introduction

From the incident solar energy of a PV panel, only 5% to 25% are converted in electricity, another significant part being reflected or converted in thermal energy. The main drawback of this phenomenon is the increase in the PV cells' working temperature which has as consequence a drop of electricity conversion efficiency. It is noted that the efficiency drops by about 0.5% for increase of 1 °C of panel temperature. The cooling of PV panels is a problem of great practical significance. It has the potential to reduce the cost of solar energy. By proper circulation of a fluid with low inlet temperature, heat can be extracted from PV modules, keeping the electrical efficiency at satisfactory values. The extracted PV modules' thermal energy can be used in several ways, increasing the total energy output of the system [4], [5], [6], [7], [8].

A simple and economical solution to PV panels' cooling is an air-type-product, where the air can be heated to different temperature levels through natural or forced flow. Forced circulation is more efficient than natural circulation, due to better convective and conductive heat transfer. In this paper, the dynamic of air cooled PV panels' temperature are experimentally investigated. In the Section 2, the experimental system is described. In the Section 3, the obtained experimental results are given, and in the section 4, the simplest thermal mathematical model of the PV panel is presented.

2. The investigated air cooled PV panel

The thermal experimental investigations were made on the PV panel BP SX 40U [1], [2]. The electrical characteristics of this PV panel are given in the Table 1, and its I-V curves for an illumination of 1 kW/m^2 (1 sun) at spectral distribution of AM 1.5, at various temperatures are given in Fig. 1. In Table 2, for a BP PV module heat capacity data are given. The frontal aria of the panel is of 0.38 m^2. Taking into account the data of Table 2, the mass of the full PV laminate could be estimated at 3.90 kg.

Table 1 – BP SX 40U Electrical Characteristics

Maximum power (P_{max})	40 Wp
Voltage at P_{max} (V_{mp})	16.8 V
Current at P_{max} (I_{mp})	2.37 A
Warranted minimum P_{max}	36 Wp
Short-circuit current (I_{sc})	2.58 A
Open-circuit voltage (V_{oc})	21.0 V
Temperature coefficient of I_{sc}	(0.065 ± 0,015) %/^{0}C
Temperature coefficient of V_{oc}	− (80 ± 10) mV/^{0}C
Temperature coefficient of power	− (0.5 ± 0.05) %/^{0}C

Table 2. The BP PV module heat capacity data.

Element of module	ρ_m (kg / m^3)	d_m (m)
Monocrystalline silicon PV cells	2330	0.0003
Polyester / Tedlar trilaminate	1200	0.0005
Glass face	3000	0.003

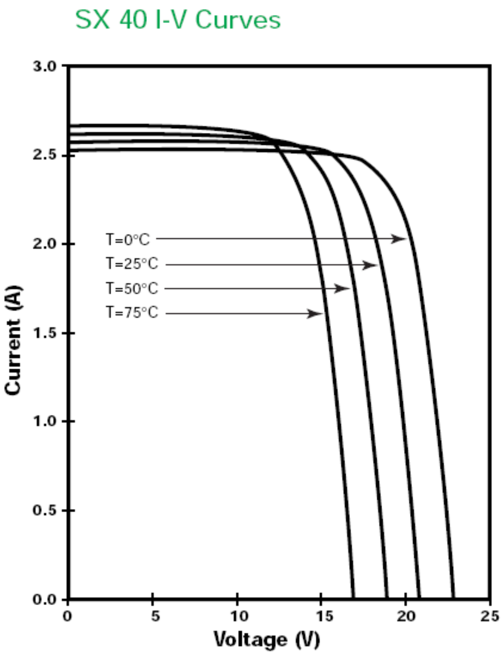

Fig. 1. The I-V curves of the investigated PV panel, for an irradiation of 1 kW/m^2, at spectral distribution of AM 1.5, at various temperatures.

The air cooling system has been added to this panel as follows. On its back side, a perforated plate was fixed. At the top of this plate, a centrifugal fan having the input power of 2 watts, as it is showed in Fig. 2, was mounted. The fan was connected to the PV panel terminals, to be powered.

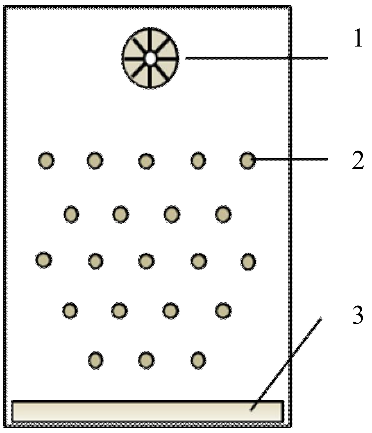

Fig. 2. The back side arrangement of the PV panel for thermal experimental investigation: 1 – a centrifugal fan, 2 – distributed air input holes, 3 – the bottom air input window.

The PV panel, equipped in this way, was exposed to the Sun, in the middle of the day, at the optimal tilt angle when the measured irradiation was 900 W/m^2.

3. The experimental results

The following measurements were made:

1. The open circuit voltage decreasing, in the absence of the forced cooling air circulation, during 10 minutes, from the moment when the PV panel was exposed to the Sun; in this time, practically, the PV panel temperature reaches its final value, corresponding to the captured solar radiation. The diagram of the open circuit voltage decreasing, in these circumstances, is shown in Fig. 3.
2. The open circuit voltage increasing, in the presence of the forced cooling air circulation, starting from the initial value due of the captured solar radiation in the absence of the cooling air forced circulation. The diagram of the open circuit voltage increasing, in these circumstances, is shown in Fig. 4.
3. The PV panel front temperature distribution, in the absence of the forced cooling air circulation, at various moments of time after its exposure to the Sun radiation, obtained with a thermo-vision camera. These temperature distributions are showed in Fig. 5.
4. The PV panel front temperature distribution, in the presence of the forced cooling air circulation, at various moments of time during its exposure to the Sun radiation, obtained with a thermo-vision camera. These temperature distributions are showed in Fig. 6.

As one can see from the Fig. 3, the open circuit voltage has decreasing from 20.8 V to 19.3 V when the cooling system with the centrifugal fun of 2 W is used. The increasing of the electrical energy delivered by the PV panel, at 2.5 A, has the value:

$$E_{inc} = (20.8 - 19.3) \cdot 2.5 - 2 = 3.75 - 2 = 1.75\, W$$

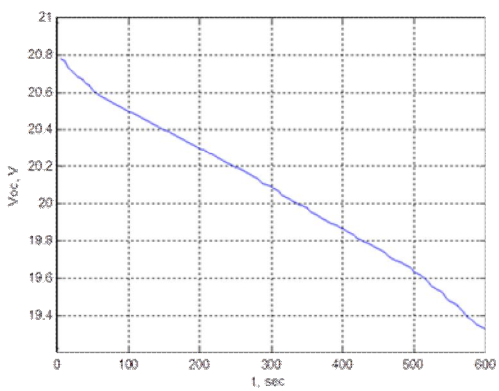

Fig. 3. The open circuit voltage decreasing, from the moment when the PV panel was exposed to the Sun, in the absence of the forced cooling air circulation.

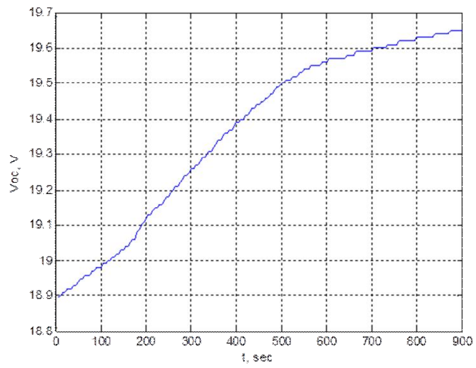

Fig. 4. The open circuit voltage increasing, in the presence of the forced cooling air circulation.

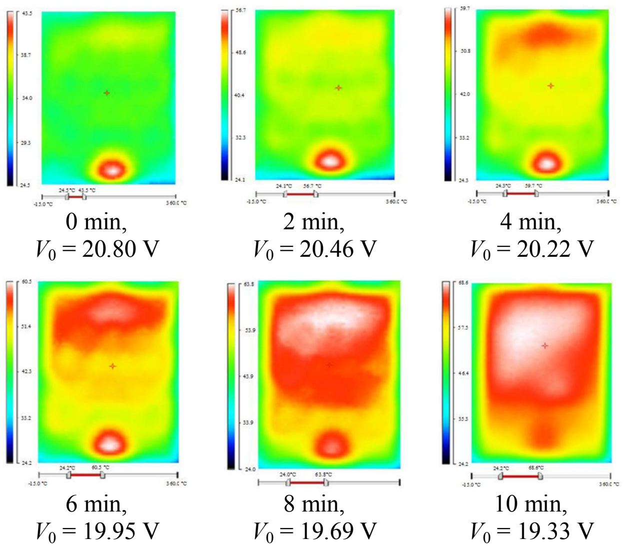

Fig. 5. The PV panel front temperature distribution, in the absence of the cooling air forced circulation.

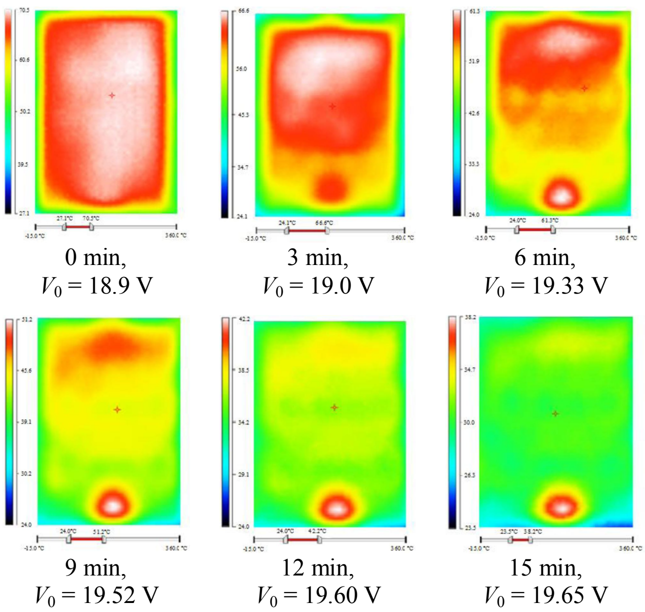

Fig. 6. The PV panel front temperature distribution, in the presence of the air cooling forced circulation; the initial value was established in the absence of the cooling air forced circulation.

The temperature distributions of the Fig. 5 and 6, by an appropriate mapping procedure, were used for the PV panel average temperature calculations. The obtained results are given in Fig. 7 and Fig. 8.

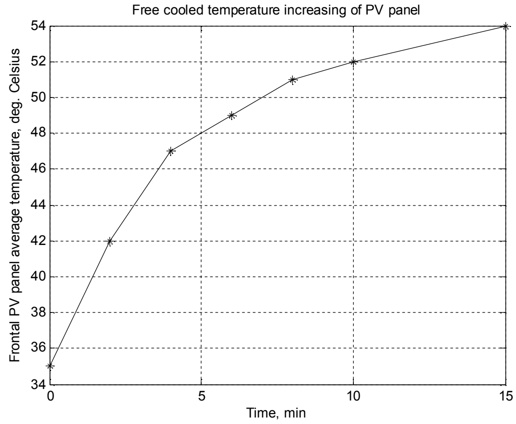

Fig. 7. PV panel average temperature increasing, in the absence of the forced air cooling, after its exposure to the Sun radiation.

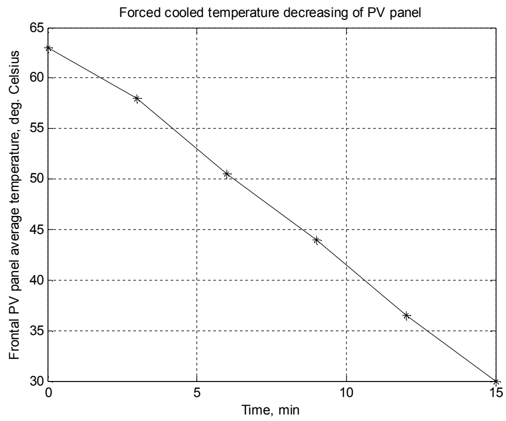

Fig. 8. PV panel average temperature decreasing, in the presence of the forced air cooling circulation, during its exposure to the Sun radiation.

4. The simplest PV panel thermal mathematical model

The simplest energy balance of PV panel is the following:

$$Q_{gen} = Q_{acc} + Q_{trs} \tag{1}$$

where Q_{gen} is the generated thermal energy, Q_{acc} is the accumulated thermal energy and Q_{trs} is the transferred thermal energy. If, for the simplicity, only the convection energy transfer will be considered, the equation (1) can be writing as follows [3]:

$$\Delta P \cdot dt = c_M \cdot M \cdot \theta \cdot dt + c_A \cdot A \cdot \theta \cdot dt \tag{2}$$

where ΔP is the incident solar power on the PV panel, θ is the PV panel temperature above the ambient temperature, c_M is the temperature accumulation constant of the PV panel with mass M of active material, c_A is the temperature energy transfer constant of the PV panel with surface aria A to the environment.

Equation (2) can be writing in the following canonical form:

$$\frac{c_M \cdot M}{c_A \cdot A} \cdot \frac{d\theta}{dt} + \theta = \frac{\Delta P}{c_A \cdot A} \tag{3}$$

For an irradiation value of 900 W/m^2, and for an environmental temperature of 30 ^{0}C, the final average temperature of the PV panel was 60 ^{0}C. As a consequence, the estimated value of the coefficient c_A can be calculated:

$$c_A = \frac{\Delta P}{\theta \cdot A} = \frac{900}{30 \cdot 0.38} = 79 \frac{W}{K \cdot m^2} \tag{4}$$

From the Figs. 3 and 7, the value of the time thermal constant of the investigated PV module, without the forced air cooling, could be estimated around the 360 s. As a consequence, the value of the c_M coefficient could be estimated:

$$c_M = T_\theta \cdot \frac{c_A \cdot A}{M} = 360 \cdot \frac{79 \cdot 0.38}{3.9} = 2770 \frac{J}{kg \cdot K} \tag{5}$$

The equivalent electrical circuit associated to the Eq. 3 is shown in Fig. 9. The value of the equivalent capacitor is:

$$C_{ech} = c_M \cdot M = 2770 \cdot 3.9 = 10803\ J / kg \tag{6}$$

And the value of the equivalent thermal resistance is:

$$R_{ech} = 1/(c_A \cdot A) = \frac{1}{79 \cdot 0.38} = 0.033\ K / W \tag{7}$$

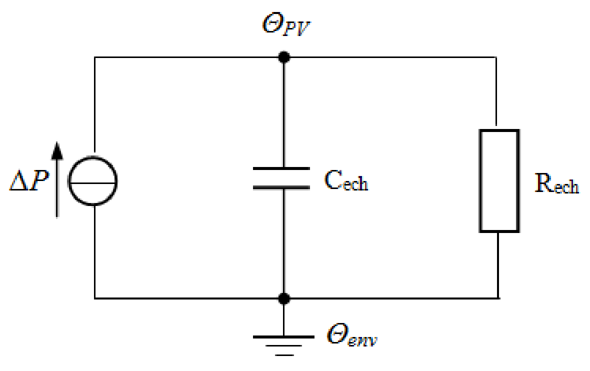

Fig. 9. Electrical equivalent circuit of the simplest thermal model of the PV panel.

Conclusion

The cooling of PV panels has increased the energy delivered by the PV panel. One has obtained an additional value of 3.75 W from which only 2 W where used to supply of 2 W fun. The supplement of 1.75 W represents a 4.37% benefit in the case of 40 W PV panel.

The simplest thermal model of PV panel was proposed. This model is a linear differential equation of PV panel temperature considering a global energy exchange. The equivalent electric circuit of the PV panel thermal model was given and the values of the model parameters where determined. The works to improve this model are in progress.

Acknowledgements

This work was realized through the Partnership program in priority domains - PN II, developed with support from ANCS CNDI - UEFISCDI, project no. PN-II-PT-PCCA-2011-3.2-1670

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